THE ROLE OF ANAMORPHISM IN THE PRODUCTION OF ORES

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INTRODUCTION.

Up to within the last few years economic geologists have been chiefly concerned with the effects of katamorphism in the production of ore in commercial quantities and have paid little attention to the part which anamorphism has played. Katamorphism comprises those chemical, physical and mineralogical changes which a rock or ore body undergoes under surface conditions. Concentration of ore by these processes results predominantly thru the elimination of other materials producing our great commercial ore bodies. Anamorphism, on the other hand, comprises those chemical, physical and mineralogical changes which a rock or ore body undergoes when subjected to conditions of high temperature and pressure. It includes alterations by dynamic regional metamorphism and contact metamorphism where the igneous mass contributed only the heat and pressure. Anamorphism, therefore, characteristically acts on materials previously formed and does not tend to the concentration or secondary enrichment of ore bodies. They are therefore commercially not important and have to some extent been overlooked. Little is known regard-

ing the behavior of ore minerals during anamorphism. Much has been done in the way of tracing metamorphosed rocks back into their original substances, and in the same way it is believed that many of the now anamorphosed ore bodies will bear a retracing into their original form.

In light of the above, it is believed that a somewhat complete summary and critical review of the known anamorphosed ore bodies of the United States is warranted, with the view of bringing out the general effects of the process on ores, and perhaps aiding in the solution of some of the problems relating to the genesis of this interesting type of ore deposit. It is purposed to consider the various types of ore deposits in which iron, copper, lead and zinc, and gold and silver occur, and then describe the anamorphosed equivalents of these where known and described in the literature. Publications of the United States Geological Survey form the chief source of information.

IRON.

General Statement.

Iron ore deposits are known to occur as magmatic segregations, as igneous after-effects, as residual limonites resulting from the weathering of igneous rocks, and as sedimentary formations. The latter occur chiefly as iron carbonates, iron silicates, but also some as oolitic ores of the Clinton type and as bog ores. From the iron carbonate and silicate rocks iron oxides are developed mainly by secondary surface alteration forming the great hematite and limonite deposits of the Lake Superior country, as well as many of the brown ore deposits scattered thruout the country. Anamorphosed equivalents of some of the above types are recognized and well known, while as to others little is known. Each of the above types will be considered in the order named.

Anamorphism of Magmatic Segregations.

Anamorphic equivalents of this type of ore deposit are not known or recognized as such or at least not found described in the literature.

Anamorphism of Igneous After-Effects.

To a large extent this type of ore body belongs in a class with the preceding, as definitely known anamorphic equivalents are not known, altho it is suspected that some of the sheared magnetites of New Jersey and the Adirondacks may well belong to this class.

Anamorphism of Residual Limonites.

CLE ELUM IRON ORES. The Cle Elum iron ores of Kittitas County, Washington,[1 & 2] furnish the only known example of the most interesting type of ore deposit, for according to Carl Zapffe, who has made an extensive study of these deposits, "the Cle Elum ores have but few counterparts in the United States and these are unimportant".

The ore bodies lie in lenticular masses between the peridotite and the Sauk formation which consists of a great thickness of arkose and a little shale with small quantities of conglomerate at the base. The ore always grades into the serpentine, generally within a foot or two, but they are not always found to grade into the Sauk formation, altho the conglomerate often contains pebbles of iron ore. Originally the beds were flat, but

[1] Carl Zapffe. Report on Cle Elum Iron Ores, Kittitas County, Wash., for the Northern Pacific Railway Company.
[2] G. O. Smith. Cle Elum Iron Ores. Transactions of the American Institute of Mining Engineers, Vol. 30, p. 356.

a subsequent major deformation has folded them into an anticline, now largely eroded, and the deposits dip in the different directions in the different places along the strike of the eroded edges of the anticline.

The iron ores are prevailingly a dull greenish black color. The variation in some of the better grades of ore is to show less green and more black or to take on a red tone, while in the poorer grades the green becomes lighter and the black gives way to brown. The ores are almost entirely magnetic, altho a little hematite occurs here and there mixed with the magnetite. The magnetic influence is usually very marked.

Zapffe finds three kinds of ores -- massive, oolitic, and laminated. The laminated ores are due to pressure, and these are therefore coarsely schistose. The striking phase is the oolitic ore, the oolites being semi-rounded grains of ore which are cemented firmly in an extremely dense, fine-grained, structureless matrix of ore. The oolites are as much as one-half inch in diameter, but prevailingly they are about one-eighth of an inch or less. The close resemblance of this oolitic character with some phase of the Cuban ores can not be too strongly emphasized in considering the origin of the Cle Elum ores which will follow later. The massive ores

are very dense, have a smooth flint-like conchoidal fracture, and greatly resemble the oolitic ore except for the oolites. Sometimes they show on fracture faces little glistening particles of unaltered remnants of siliceous minerals of the original rock. The massive and oolitic phases are about evenly distributed.

Chemically the ore consists of about an average of 41% iron, with phosphorus extraordinarily low and sulphur practically negligible. Manganese is low, with calcium, magnesium and the alkalies not in deleterious amounts. Nickel, cobalt, and chromium are present in variable small amounts, and each of these gives an increased value to the steel made from ores containing them.

From the field relations of the ore deposits and the underlying rock formation, from a comparison of the chemical analyses of the ores with those of the peridotite and serpentine, and because of the extensive alteration of peridotite to serpentine, Zapffe concludes that the iron ore was derived from the original peridotite rock purely thru a process of rock decay in situ. He admits the doubtful possibility that the decayed material was subjected to a subsequent assortment by wave action in an inland sea. The ores were then buried deep-

ly under later formations and also subjected to dynamic stresses, thereby becoming dehydrated, hardened, and in part rendered magnetic.

Discussion. From the foregoing facts it can readily be seen that anamorphism has done little in the concentration of these ores. The chief concentration took place during the process of rock decay, a purely katamorphic process. Katamorphism thru the processes of carbonation, hydration, oxidation, and solution materially alters the chemical composition of a rock as well as its mineralogical and physical characters. Outside of dehydration and some deoxidation the anamorphism has little effect on the chemical composition of a rock; it merely rearranges the elements present into more stable forms to meet the new conditions under which the rock is brot. The mineralogical and physical characters are, however, materially changed.

With the natures of the two opposing processes in mind, we can draw some conclusions as to what took place in the development of the Cle Elum ores into their present form. If Zapffe's conclusions regarding their origin be correct, then we may assume that the ores were, before anamorphism, soft, hydrated, highly ferruginous clays with plastic, earthy and granular textures. Chem-

ically, by anamorphism, the ores were dehydrated and to some extent deoxidized. The chief mineralogical change appears to be the formation mainly of magnetite with some hematite from limonite. The formation of other anhydrous silicates, from the impurities of the ore, has not been mentioned in any of the descriptions noted. Physically, there was a great reduction in pore space, the ore becoming hard, dense, and in part crystalline and schistose.

Thus the concentration of the iron by anamorphism, such as it is, is only relatively due to the loss of water and oxygen and the reduction of pore space.

Anamorphism of Iron Carbonate and Silicate Rocks.

GENERAL STATEMENT. Iron carbonate and silicate rocks occur as extensive formations in all the iron-bearing districts of the Lake Superior region,[1/] the silicate or greenalite rock occurring predominantly in the Mesabi district. In many places these formations have been altered to ore chiefly by surface agencies. In other places they have come in contact with large masses of igneous material or have been subject to great pressure and by

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1/ Van Hise, C. R. and Leith, C. K. Geology of the Lake Superior Region. U. S. Geol. Survey, Mon. 52, 1912.

these means have been altered into various forms, the chief one of which is known as the silicated magnetite rock. Of the two processes named, that of contact metamorphism is by far the most far-reaching, dynamic forces having changed the rock little if any, for much of the original carbonate and silicate rocks which have been subjected to this process are still to be found little changed where superficial agencies have not been able to attack them.

Rocks of this type anamorphosed by igneous masses occur chiefly in the eastern Mesabi, western Gogebic, western Marquette districts, and in the Gunflint district of Minnesota.

Eastern Mesabi District,[1/] Minnesota. As one goes east from the Mesabi station the iron-bearing formation takes on noticeable changes. The predominant taconite gives way to a banded, dense, hard, crystalline rock composed of quartz, amphibole, and magnetite in varying proportion. These rocks are found to lie in contact with Keweenawan gabbro and granite.

For the field relations of the rocks and from the

1/ Leith, C. K. The Mesabi iron-bearing district of Minnesota. U. S. Geol. Survey, Mon. 43, 1903.

chemical and mineralogical composition of the amphibole magnetite rocks, Leith concludes that they were derived from the alteration of the original greenalite rock in contact with the granite and gabbro. The alterations were those of partial oxidation, perhaps deoxidation, dehydration, decarbonation, and silication, characteristic of such conditions. The greenalite was altered without the presence of sufficient oxygen to bring the iron up to the ferric state, and resulted in the development of magnetite. Contemporaneously along with this occurred the development of amphiboles such as grünerite, actinolite, cummingtonite and so forth, from the greenalite by dehydration and the redistribution of the calcium, magnesium, iron and silica in the granules and matrix. Where there was some carbonate present the development of the amphiboles involved decarbonation and silication. Recrystallization of the chert and matrix resulted in the coarsening of the grain, and during recrystallization there was a marked tendency of minerals of the same kind to segregate into bands giving the rock one of its most important characteristics.

Western Gogebic District, Wisconsin. Chiefly on the western end of the range, but to some extent on the eastern end, the iron-bearing formation is found similar in most respects to the silicated magnetite rock of the Mesabi Range. And like on the Mesabi Range, the formation is found resting in contact with a great mass of igneous material supposed to be an intrusion of Keweenawan age. A similar origin is ascribed to these rocks as for those on the Mesabi, the only great difference here being that the original rock was chiefly iron carbonate instead of iron silicate, and that the chief chemical changes were an insufficient oxidation of the carbonate-forming magnetite and a decarbonation and silication of the same to form amphibole. An average chemical analysis for these rocks is given in Monograph 52, page 241, and shows an iron content of 41.95%. The analysis on the whole is found to be very similar to those of the ferruginous cherts found farther to the east, showing quite conclusively that very little if any material was introduced during contact action, and that the chief process involved was a recrystallization with a redistribution of the elements present.

Western Marquette District, Michigan. These rocks occur chiefly in the western portion of the district but also in the eastern portions where under the influence of igneous intrusion the carbonate rocks were altered for some distance on all sides of it. Since they are similar in all respects to the silicated magnetite rocks of the Gogebic district, they will be passed with bare mention.

Gunflint District, Minnesota.[1] Perhaps nowhere in the Lake Superior district is there as good an opportunity for studying the metamorphic effects of the gabbro intrusion and its associated sills. Petrographically, the original iron-bearing formation consisted of sideritic chert similar to that found in the Gogebic and Marquette districts, and is now still found near Gunflint Lake. Westward towards the Paulson mine the rock becomes black or dark-green, coarsely crystalline, and banded, consisting essentially of magnetite, fayalite, cordierite, quartz and iron carbonate in varying proportions. Other rare minerals are found, and have been described by Zapffe.[2] The principal hope for ore is centered near the Paulson

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[1] Leith, C. K. The Geology of the Lake Superior Region. U. S. Geol. Survey, Mon. 52, 1912, pp. 198-204.

[2] Zapffe, Carl. Unpublished thesis, University of Wisconsin, 1908.

mine where the ore is as above described. The analysis shown again closely corresponds with the ferruginous cherts of the Mesabi. Bands of the formation a few feet thick run as high as 50 or 55% in iron. At the bottom of the formation, where it rests against the greenstone, a 3-foot layer is encountered running above 55% in iron. The thinness of the ore bodies, the highly crystalline, silicated magnetic character of the ore, and the locally high sulphur, preclude the use of the ore under present conditions. On the other hand, the total tonnage is large, the phosphorus content low, and it lacks titanium. Magnetic concentration may make this ore available for future use.

DISCUSSION. Consideration of these four districts shows that anamorphism acting on the original carbonate and silicate rocks does not produce a concentration of the iron content, further it produces a rock of such a character that later katamorphic prodasses find it difficult to act upon. Chemically we find that there is a partial oxidation with decarbonation, dehydration, and silication. Mineralogically, the carbonate and greenalite give way to magnetite and the various amphiboles and other silicate minerals. The chert has recrystallized and has become coarser in grain. Physically there has

been a segregation of the various constituents into bands, as well as a decrease in pore space and an increase in density. Prospects of finding ore in commercial quantities in these formations lie only in finding the anamorphosed equivalents of beds originally high enough in iron to be classed as ore under the present conditions. On the other hand, as the tonnage is large, the phosphorus content low, and no titanium present, these formations may become producers of ore when cheap methods of concentration are invented and when the demand for ore becomes more pressing.

Llano-Burnet Region,[1/] Texas. The deposits are located in central Texas in what is supposedly an Algonkian series and known as the Llano series. They consist of a lower gneiss and an upper schist series, all supposed to be the products of highly metamorphosed sedimentaries. Intrusive into these are granites, granite porphyry, as well as some of a more basic nature. The rocks now consist of a series of mica, amphibole, and graphite schist, crystalline limestone and feldspathic schist resembling quartzite. The structure consists of two northwest-southeast trending anticlinal folds.

1/ Sidney Paige, Mineral Resources of the Llano-Burnet Region, Texas. U. S. Geol. Survey, Bull. 450.

The iron deposits, so far as could be observed, are an integral part of the Llano series and exhibit much the same relationship to the other member of the series as do the limestones and graphitic schists. They are tabular in form and are typically layered or stratified ore bodies conforming in attitude with the layering of the somewhat schistose rocks by which they are enclosed. They vary in thickness and iron content as do the graphite-bearing strata in carbon, and locally grade into surrounding country by a gradual decrease in iron. No locality was observed where beds in which ore occurred cut across neighboring beds, as might be expected in case of intrusion. There are interbedded with the ores, barren or lean layers composed of the same minerals as the gangue of the ores.

The ore-bearing rock is a crystallized granular schist or gneiss which, so far as observed, has undergone the same degree of metamorphism as the other beds of the series. The ore occurs as more or less concentrated grains of magnetite (or hematite in part) with quartz, feldspar, and a little biotite. The magnetite seems to have crystallized either just before or simultaneously with the feldspar and quartz.

The author, after considering the three possible hypotheses which might explain the origin of these ores, concludes (1) that the beds do not represent igneous segregations from a granitic magma, (2) that they do not represent replacements of sedimentary beds, either before or during metamorphism, due to emanations from a granitic magma, but (3) that they do represent metamorphosed iron-bearing sediments. It is the author's view that the ore was first deposited as oxide, carbonate, or glauconite, etc., with the sediments either in extended basins or along borders of the sea, and that subsequent deep burial with following folding and metamorphism altered them into their present form.

Discussion. Since little is known concerning the original character of the iron ore deposits little can be said of the chemical, mineralogical, and physical changes. Judging from the high potassic content of some of the lean ores, the author suggests the possibility of a derivation from siliceous glauconitic sediments. That glauconite is capable of altering to magnetite is proven by the work of J. K. Prother in describing the greensands of New Jersey.[1/] The author believes that it

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[1/] Jour. Geol., Vol. 13, p. 511.

would seem extremely possible that if siliceous glauconite beds, similar to those of the Cap Mountain formation, were subjected to metamorphic conditions, potassic feldspars, quartz, and magnetite would result such as are found in other ores of the Llano Burnet district.

Anamorphism of Iron Oxides Derived Chiefly from Surface Alteration of Carbonate or Silicate Rocks.

GENERAL. Ore bodies produced thru the agents of katamorphism are sometimes brot under the influence of intruded igneous mass, or are subjected to great stresses due to deep burial and mechanical movement. The results produced by each, tho not essentially different, will be considered separately. Of those deposits affected by intrusions and those which produce ore at the present time, only two are known, -- Republic district and the Champion mine, both located on the Marquette Range of Upper Michigan. Of those deposits effected by dynamic metamorphism, those located in the Ely trough of the Vermilion district, and those along the contact of the Upper Negaunee and the Upper Huronian, will be considered.

CONTACT METAMORPHOSED ORES.

Republic District of Michigan.[1/] Prior to the deposition of the Upper Huronian sediments there was emergence and certain portions of the Negaunee formation were exposed to surface conditions and in parts changed to ore and ferruginous chert, while other parts remained as the cherty iron carbonate, the original form. The Upper Huronian was then deposited and the conglomerate at the base was to a large extent made up of fragments of ore and ferruginous chert. After a time these deposits were changed by the igneous masses which intruded them. The ore itself was rendered magnetic and specular by recrystallization, the ferruginous cherts altered to brilliant red and black jaspers, and the original carbonate unexposed to previous surface action was altered to amphibole-magnetic rock. In all the alterations noted, rock flowage incident to folding and intrusion have aided the direct contact effects.

Champion Mine, Michigan.[2/] The development of the magnetite ore deposits here is explained in much the same way and a repetition of the discussion of its occurrence and origin is unnecessary.

1/ Monograph 52, p. 552; also Monograph 28, Chap. VI.

2/ Monograph 52, p. 553; also Monograph 28.

DYNAMICALLY METAMORPHOSED ORES.

The Vermilion and Upper Negaunee Ores. The alterations of the ferruginous cherts and ores under mechanical pressure have been very conspicuous in these two districts. The Vermilion ores have, at Soudan Hill, been rendered hard, crystalline, dehydrated, and locally somewhat schistose, more or less magnetic, locally brecciated, and cemented by vein quartz and later by iron oxide, both hematite and magnetite. The ferruginous cherts have simultaneously been recrystallized and cemented, and the iron minerals have gone thru the same series of physical and chemical changes as in the ore. The net result has been the production of a rock having a composition similar to that of the ferruginous cherts, with a large proportion of magnetite and with a small amount of pore space.

In the Marquette district the post-Huronian folding developed a marked shear zone at the contact of the Negaunee formation with the overlying detrital ferruginous base of the Upper Huronian, with the result that the ore was dehydrated and rendered crystalline, developing coarsely specular hematite or micaceous hematite and porphyritic magnetite, accompanied by a marked elimination of pore space. The extent of mashing is best

seen in the flattened pebbles of the Upper Huronian. The effect on the ferruginous cherts or jaspers has been to make the iron brightly specular.

<u>DISCUSSION.</u> This type of ore deposit, tho relatively more important than any of the preceding, has again been formed chiefly by the agents of katamorphism and only changed slightly under anamorphic conditions, conditions which do not favor the transfer and segregation of materials to any great extent. Locally there is evidence of a transfer of iron under these conditions, as is shown in the fact that the cements of the fractures are chiefly magnetite and that the iron is usually in coarser bands. So far as the iron-bearing formation has been previously altered and concentrated to ore under weathering conditions, contact action or dynamic metamorphism has only the effect of dehydrating and recrystallizing the ores, but not of further concentrating them.

Anamorphism of a Secondarily Infiltrated Limonite Deposit.

TALLADEGA GRAY ORES.[1/] The gray iron ores of Talladega County, Alabama, constitute the only deposit of this type found in the literature. They occur in a narrow belt that is confined almost entirely to Talladega County in a folded series of slates and quartzites which have an easterly dip and a general north-south strike, at least where most of the ore is now obtained, i. e., at the Mesabi Mine, the only mine operating at the time the report was written. The strike, however, varies from north-south to east-west, as does the dip, owing to deformation thru folding and faulting.

The ore occurs in two veins, the easternmost one being from 10 to 15 feet thick and now uncovered for about 600 feet along the strike. The westernmost vein is wider, being 42 feet wide due to a reduplication of the beds by thrust faulting. Several other small veins occur in this county, altho little development work has been done.

1/ P. S. Stose. The Gray Iron Ores of Talladega County, Alabama. Extract from Bull. 315, U. S. Geol. Survey,

The ore occurs in two forms; the first rather hard, massive, and quartzitic; the second soft, crumbly and slaty. The soft ore is generally higher in iron and is more easily mined, and has undoubtedly been formed by the replacement of slate by iron. The hard and massive ore breaks into angular blocks bounded by joints. On freshly fractured surfaces the ore is seen in glistening small crystals interspersed with quartz grains. The quartz grains are crushed and elongated in the plane of cleavage.

Practically all the so-called Talladega gray ore is really hematite. An analysis made in the chemical laboratory of the United States Geological Survey of No. 2241, an average sample of ore from the Heacock Mountain, Weewoka Hills, gives 70.04% of Fe_2O_3 and 0.74% FeO. If all the ferrous iron in this analysis is derived solely from magnetite the relative percentages of the two minerals would be 97% hematite and 3% magnetite. In places, however, the relative percentage of the magnetite so increases that the ore becomes somewhat magnetic.

The main constituents of the ore are quartz and hematite, the latter occurring in scaly and apparently sheared aggregates while the magnetite is generally in

well-formed sharp crystals, which have been formed later than the hematite. In a very few thin sections iron sulphide has been recognized. The quartz occurs in two distinct forms -- as an original mineral very much strained and shattered, and as a secondary mineral showing optically no stress. This secondary quartz includes many crystals of magnetite, the relation of these showing the relative ages of crystallization. Mica was apparently contemporaneous with the later quartz and these two minerals together with the magnetite were probably formed at the close of the period of dynamic metamorphism during which the mountains were built. Thin sections of ore show, beside the above named minerals, the presence of some soda-lime feldspar and microcline, as well as the practical absence of biotite, the mica present being muscovite.

Regarding the origin of these ores the author concludes that the gray ores in some stage of their development have been hydrated iron ores, and that their present form is due to dehydration of the original limonite by heat and pressure produced by the regional deformation. The belief that the gray ores were at one time in the form of limonite is based mainly on their field occurrence. In many parts of the district brown ore deposits occur at

essentially the same geological horizon as the gray ores, and in a few places this connection is so close that the gray ores can be traced into brown ore. The composition of the ores with their high phosphorus and silica content is also strongly suggestive of their common origin.

While the gray ores have probably been thru the limonite stage, it is not believed that the limonite was necessarily the original form in which the iron was deposited. This point is shown at one place on the northwest flank of the Kahatchee Hills where after a few tons of brown ore had been removed from a bed of quartzite the ore gave way to disseminated pyrite. The limonite was here undoubtedly the residual concentration remaining after the decomposition and oxidation of the pyrite. Moreover, along the strike not over a hundred yards distant, there is a bed of quartzitic gray ore which seems to be a direct prolongation of the bed of pyrite. In this place at least the author believes that the gray ores were derived from the pyrite, perhaps having been limonite in an intermediate stage. He also admits the possibility of a direct derivation of the gray ores from pyrite, and in support of his view he cites Van Hise, who shows that oftentimes the sulphides may be directly converted into hematite by heat and pressure. Evidence showing that

limonite is an intermediate stage in some places is afforded by the ore itself where it shows areas of limonite that were apparently derived from iron sulphide.

From the facts just presented, it would seem that the ores are perhaps derived from two sources. The first of these is pyrite, which may have been formed thru the precipitation of iron solution by the decomposition of organic matter in the quartzite. The second and by far the most important source was limonite which collected in certain horizons where relatively impervious strata succeeded relatively porous beds, and so arrested the free circulation of the ore-bearing solutions. These limonite beds were subsequently metamorphosed by the great folding and fault movements that the region suffered during the period of mountain building. Where the metamorphism was moderate the limonite was simply dehydrated into hematite, and where it was more intense some of the oxygen was apparently driven out and the limonite was changed to hematite with some magnetite. In support of this theory Stose cites, that at Columbiana, where the rocks are but slightly metamorphosed, the ore is practically a reddish hematite with hardly any magnetite, while in the range near Mesabi the rocks are more metamorphosed and the magnetite increases parceptibly, and in still an-

other range in the very highly metamorphosed belt near Chulafinne, Cleburne County, an iron ore which seems to occur under nearly the same conditions, is almost entirely magnetite.

Discussion. As was the case with the Cle Elum ores, we find that katamorphic processes have played the chief rôle in the formation of the Talladega ores. Before anamorphism these ores must have been in the form of soft limonitic material forming a sort of cement to the quartzitic bed in which the ores are found. Chemically the ores were dehydrated and to some extent deoxidized. Mineralogically the limonite was changed to hematite and a little magnetite. From the impurities, such as clayey material, muscovite was formed. Physically the ore was rendered hard and crystalline. The quartz grains were strained and shattered and the rock as a whole broke up into angular blocks. Little if any actual concentration of iron took place during the process.

Production and Reserves of Anamorphosed Iron Ores.

Thus far most of the production from these types of deposits have come chiefly from the anamorphosed equivalents of iron oxides from the Lake Superior country, constituting the hard, massive and specular hematites. In 1906[1] these comprised 7% of the total production from the Lake Superior region and came chiefly from the deposits described.

For the Cle Elum ore tonnage estimates are given by Zapffe[2], varying considerably depending on the assumption to which the ore goes and the continuity along the strike. His estimates run up to 12,754,000 tons.

The average content of iron would be about 41.18%. In making the calculations 10 cubic feet per ton were used by Zapffe to reduce volume to weight.

No figures were available for the productions of the Llano-Burnet region of Texas, nor for those of the Talladega gray ores of Alabama, and as these are yet only in the development stage nothing can be said of the reserves altho indications are quite favorable at some of the workings.

1/ Geology of the Lake Superior region, U. S. Geol. Survey, Mon. 52, 1912, p. 479.

2/ Carl Zapffe, Report on Cle Elum Ores.

COPPER.

General Statement.

In searching thru the literature on copper deposits it was soon learned that a distinction must be drawn between those deposits associated with amphibolitic rocks and supposed to have been derived from them by anamorphic processes, chiefly dynamo-metamorphism, and those deposits formed prior to the deformation and only modified slightly by anamorphic processes. Copper occurs in primary deposits chiefly as replacement deposits at the contacts of igneous masses with sedimentaries usually limestone, as fissure veins, as disseminations in shear zones and in schists. Further, these deposits are in places oxidized and in some places changed thru processes of secondary sulphide enrichment. There is even reason to believe that each one of these primary and secondary types has an anamorphosed equivalent and is to be found chiefly in the older rocks of the lithosphere.

Those of the first class are interesting and important chiefly because of their somewhat unique origin.

Ore Bodies Formed as the Result of Anamorphism.

ORE OCCURRING AS DISSEMINATIONS IN AMPHIBOLITIC SCHISTS. The Encampment District, Montana.[1/] The copper deposits, here known as the Hinton type, occur in hornblende schists, the oldest rocks in the district, and are supposedly derived from volcanic lavas and fragmental tuffs by regional metamorphism. They contain sulphides of iron and copper in small amounts in the form of disseminated grains or lenticular impregnations. Promising ore bodies of this type have been found at Creede, Island City and Lucky Find, Sun Anchor and Verde, Hinton, Itmay, and North Fork.

From the general occurrence it is concluded that both amphibolite and the ore are of contemporaneous origin with the general recrystallization of the rocks in which they occur, and that the ores originated during regional metamorphism at a very ancient period prior to Cambrian time.

In support of the above conclusion the author, A. C. Spencer, presents the following evidence.

1. "The zones bear no observable relation to the

1/ Spencer, A. C. Copper Deposits of the Encampment District, Wyoming. U. S. Geol. Survey, Prof. Paper 25, 1904,

presence of igneous rocks which may occur in the same general region, and where the schists are cut by intrusives no distinct contact minerals are developed. Therefore they can not be attributed to contact metamorphism."

2. "The lodes are not separated from the enclosing schists by gouge or by distinct walls, so they can not be filled fissures."

3. "There are no veinlets of quartz or other minerals which appear as tho filling cracks in the rock, showing that zones have not been fractured and afterwards cemented by mineralizing solutions."

4. "The bodies invariably follow the stratification of the original rocks, which is found to be parallel to the present slaty structure of the metamorphic schists. The structure, therefore, controls their direction."

5. "Examined in detail the material of the lodes themselves is found to be schistose, thru the arrangement of the component minerals in parallel planes. A considerable amount of hornblende similar to that of the enclosing schist is usually present in the zone, and epidote, which is particularly associated with the ore, occurs in small amounts thruout the country rock. The lodes seem, therefore, to form an integral part of the schist series, and they are regarded as having been formed by the same causes and at the same time as the remainder of the series."

6. "The beds involved in the mineralized zone must have differed in their original composition from the mass of the rock which has produced the hornblendic portion of the schist. This is shown in all cases by the preponderance of epidote and garnet, both of which indicate a high proportion of lime in the material from which they were derived. Furthermore, at the Hinton property a stratum of fairly pure crystalline marble, and another of quartzite occurring in the midst of the lode, bear out the deduction that the distinct character of the mineralogical aggregates is merely an expression of original differences in composition."

7. "The metallic sulphides are shown by the microscope to have crystallized contemporaneously with the silicate minerals of the rock. The metallic substances must therefore have been introduced at the time of metamorphism when the original materials of the present schists were being formed by recrystallization."

Regarding the source of copper for these deposits, the author excludes their possibility of coming from the gabbro masses, because they have been proved to be absent when the recrystallization took place. Likewise the possibility of the siliceous rocks as being the source is

excluded, and also because these are not characterized by the presence of copper minerals. He, therefore, believes that the copper which the schists now contain, so far as its minerals are of contemporaneous origin with their metamorphism, was derived from the original rocks from which they were formed. The possibility of an unknown source is also recognized.

Of all these deposits, that of the Hinton appears the most favorable. The grade of the ore here runs about 8.18% copper, and 40¢ in gold. The gossan of the vein, which is very shallow, consists of a spongy iron oxide mixed with decomposed and iron-stained garnet, and with other minerals of the lead which are relatively fresh in appearance more or less distributed thru it. Practically no secondary sulphides were encountered, and unaltered chalcopyrite occurred in one instance within 12 feet of the surface. The very superficial extent to which the vein has been leached by surface waters, is undoubtedly due to the very tight nature of the ground, the lead having no gouge or slip along its walls. From the strength which the lead exhibits in outcrop, and from the fact that the richness of the ore which occurs, tho moderate, is not due to secondary enrichment, it may be expected that it will continue to a considerable depth.

Copper Deposits in Chaffee, Fremont, and Jefferson Counties, Colorado.[1/] From the description of these deposits their similarity to those of the Encampment district are somewhat striking. W. Lindgren, in describing these deposits, says that they are not of commercial importance, but are from their genetic standpoint.

The geology consists of pre-Cambrian granites, gneisses, schists, and pegmatites. These contain some basic intrusions now amphibolitic schists. Locally they form as chloritic, micaceous, and staurolitic schists, many of which contain garnets.

The ore deposits are, according to Cross, "a thick bed of actinolitic schist richly impregnated with copper minerals." The ore body lies conformable with the schist and is practically a flat lens 800 feet long and at most 150 feet thick. Much 2% ore still remains.

The ore generally consists of a mixture of limonite, malachite, cuprite and chalcocite, with remaining unaltered grains of chalcopyrite, which evidently is the original mineral. There is no well defined zone of chalcocite. A little zinc blende, galena, and cerussite occur in places. The ore carries very small amounts of gold and silver.

1/ Lindgren, W.. Copper in Colorado. U. S. Geol. Survey, Bull. 340, pp. 157-174.

The footwall consists of a fissile biotite schist. Next lie irregular masses of a dark green, fine-grained amphibolite composed of bluish green and colorless amphiboles, and of grains of labradorite, possibly also other feldspars and some disseminated particles of magnetite. The structure is diabasic and typical of a basic schist. Then follow several feet of a heavy dark zinc blende ore, which under the microscope shows reddish brown sphalerite and a little chalcopyrite intimately intergrown with about equal quantities of bluish green and colorless amphibole. The bulk of the ore is massive and contains both zinc blende and chalcopyrite with about 10% of magnetite and some pyrite. As broken the ore is said to contain about 20% zinc. Under the microscope the ore shows irregular masses of reddish garnet penetrated by prisms of colorless monoclinic amphibole, which is also intergrown in the manner of the crystalline schists making up the bulk of the rock. These two minerals contain grains of chalcopyrite, pyrite, magnetite, and zinc blende in relations indicating simultaneous formation with the minerals of the crystalline schists. Towards the hanging wall the ore gradually becomes poorer and changes into a normal garnet gneiss.

In his summary and discussion of genesis, he says

that the micaceous schists are of sedimentary origin and that into these large masses of gabbro were intruded. The magma contained copper, and some of the dikes intruded into the folded sediments surrounding the igneous masses were products of differentiation rich in copper sulphides. The Sedalia ore deposit is supposed to be such an ore located along a dike. The ore follows approximately, but not strictly the planes of stratification. Renewed dynamo-metamorphism following the intrusion accentuated the conversion of the sediment into crystalline schists and changed the peripheral parts and dikes of the intrusion into amphibolites. The ore minerals were recrystallized and migrated in part thru the wall rocks, the contents being made indistinct by pressure and rearrangement of minerals.

Continuing further, he says that in its present form the deposit is assuredly a product of pre-Cambrian dynamo-metamorphism, and to judge from the position of the covering of Paleozoic crust blocks near Turret, the portion now worked, was at least 15,000 feet below the surface upon which the Cambrian and Carboniferous rocks were deposited. It was probably much farther below the surface of the earth at the time of the intrusion. The intrusion and regional metamorphism was followed by enor-

mous intrusions of granites which seem barren of mineral deposits. Pressure continued after the consolidation of these rocks, and they were made partly schistose. The last feature of the pre-Cambrian intrusion was the pegmatitic dikes. These are likewise barren, and one of them cuts the Sedalia deposit in two.

Concerning their oxidized form he says that active oxidation has converted the upper 200 feet of the deposit into copper carbonate and chalcocite mixed with the residual sulphides. The water level is at present below the lowest tunnel.

Similar deposits to the Sedalia are found at Turret, Cleora, and the Cotopaxi.

The pre-Cambrian deposits of Jefferson County as shown by the Malachite Mine are in a gabbro dike containing magmatic sulphides later than the main mass of schists, but probably earlier than the pegmatites. All the copper deposits are regarded by Lindgren as differentiation products of a basic magma in places changed and rearranged by dynamo-metamorphism.

Copper Deposits of the Santa Fe Range and Upper Pecos River, New Mexico.[1/] The deposits of these local-

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1/ Lindgren, Graton, and Gordon. The Ore Deposits of New Mexico. U. S. Geol. Survey, Prof. Paper 68, 1910, pp.110-114.

ities closely resemble those just described and are thot to have a somewhat similar origin. The Hamilton mine, the most extensively developed and best described mine of the area, occurs in a zone or belt 60 feet wide in the amphibole schist and parallel to its strike, or N. 50° E. In this belt the amphibolite changes in places to chlorite schist. It contains large scales of biotite and needles of tourmaline, as well as irregular masses of pyrite, chalcopyrite, and zinc blende. The best ore, some of which has been shipped, is said to contain 17% copper, but the average of the whole is of low grade. The ore in places carries gold to the extent of a few dollars a ton, especially where it is more quartzose. The silver content is said to average 5 ounces per ton.

Some of the ore consists of coarse dark-green hornblende of varying grains, intergrown with pyrite and chalcopyrite. Quartzose streaks of unoxidized ore contain a mosaic of quartz grains with cubes of pyrite, the latter intergrown with a pale green mica, probably a biotite. Other specimens contain, in a fine grained amphibolite, well developed prisms of bluish gray tourmaline inclosing grains of pyrite and hornblende. A zinc blende of very dark color accompanies the hornblende and chalcopyrite. Galena occurs sparingly.

The intergrowth of the ore minerals with the hornblende of the amphibolite, and the absence of well defined fissures make it evident that the metallization was almost contemporaneous with the metamorphism which produced amphibolite from some dioritic or diabasic rock. The appearance of biotite and tourmaline as gangue minerals indicates, moreover, the presence of conditions of high temperature and pressure during ore formation. It is suggested by the author[1/] that the metal may have originally been contained in the basic magma and that its concentration was effected during metamorphism. At the Maillenchet prospect the granite is believed to be intrusive into the amphibolite, and perhaps this rock has produced great metamorphic effects, as shown by the presence of tourmaline in the ore. Whether the granite was the source of the copper is not known definitely. It seems to be the view of the author, however, that they were derived from the basic magmas, now amphibolites, and concentrated during metamorphism. The age of these deposits is thot to be of undoubted pre-Cambrian, as shown by their relations to the Carboniferous strata and the general history of the district.

1/ Waldemar Lindgren.

Copper Deposits of South Mountains, Pennsylvania[1]

There seems to be a great difference of opinion concerning these deposits, and in describing them at this place it is only done to present the views of the author, J. W. Stose. His views, if correct, would allow their classification as an ore deposit formed during anamorphism of an original copper-bearing rock, here basic lava flows. The following is abstracted from his description given in the reference mentioned below.

"The copper occurs as native in the pre-Cambrian eruptive rocks. The ore is associated chiefly with large basic eruptives and occur generally at or near the contact with acid lavas. The copper is found native in little blebs, grains, or wires filling the amygdules or joint planes, and as impregnations in the country rock in the highly altered zones in the epidote."

Stose believes that the copper was disseminated in minute particles in the rock probably as sulphide, and that in pre-Cambrian time and again in late Carboniferous these rocks were subjected to great compression and heat, and in the presence of heated waters the original minerals were altered. The hornblende was changed

[1] U. S. Geol. Survey, Bull. 430, pp. 122-31.

to chlorite, the feldspars and ferro-magnesian minerals reacted and formed epidote and quartz rocks. The disseminated copper was concentrated and is found in flakes in the filling of the amygdules or joint planes and as impregnations in the country rock, especially in the epidote phase. Transportation and concentration of copper must have been effected by solution, and it is his belief that the sulphide was dissolved as sulphate, and possibly changed to carbonate or silicate. Precipitation is thot to have been caused by over-saturation, lowering of the temperature, or reaction with precipitating agents on the wall rock. From the massive layers of copper-bearing epidote and the small blebs of copper, epidote and quartz in the center of relative fresh rock, he concludes that they are the result of deep-seated alteration under the influence of probably heated waters.

Weed[1/] regards similar occurrences in the same belt of pre-Cambrian in Virginia as recent concentrations due to downward-moving waters of surface origin, limited to shallow depths where leaching has gone on. This is well brot out in the vicinity of Fort Royal, where mining has shown that the epidotization is primarily a surface phe-

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1/ Weed, Walter Henry. Copper Deposits of the Appalachian States. U. S. Geol. Survey, Bull. 455, p. 15.

nomenon, tho it may extend downward along shear zones to a considerable depth. In his opinion there seems to be good reason to believe that some of the irregular isolated bunches of ore and all of the little veinlets filled by serpentine were produced by tension resulting from the expansion of the rock, due to serpentinization which has increased its volume, roughly speaking about one-third. The epidotization appears to be a later phenomenon and to be due mainly to surface waters. It is closely connected with the appearance of native copper and copper oxide more rarely of bornite and chalcopyrite. At localities where copper ore is found the deep workings show bunches and stringers of calcite and serpentine but no copper; the various transitions may be observed to the surface ores, with gradual replacement of calcite by copper as a result of the action of infiltrating waters.

ORE OCCURRING AS REPLACEMENTS OF LIMESTONES NEAR AMPHIBOLITIC ROCKS.[1/] Planet, Signal, and Little Butte Properties, Arizona. Closely related to the preceding deposits we find those now to be described occurring in ore deposits of northern Yuma County, Arizona. The most

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1/ Bancroft, Howland. Reconnaissance of the ore deposits in northern Yuma County, Arizona. U. S. Geol. Survey, Bull. 451.

extensive copper and iron deposits occur in a series of sedimentary beds and associated amphibolites and chloritic schists which overlie the oldest pre-Cambrian complex of granites and gneisses. The Planet, the Signal and the Little Butte properties represent the principal replacement deposits in limestones.

Owing to deep and thoro oxidation which all of these deposits in this region have suffered it is difficult to ascertain the primary constitution of the ore, but it is probable that in all cases the important minerals were specularite, pyrite, and chalcopyrite containing very small quantities of precious metals. In all of the deposits the gangue minerals are chiefly specularite and quartz with some calcite, and the principal ore minerals are chrysocolla and malachite, which are intimately mixed with the specularite. Occasional specks of chalcopyrite, pyrite and bornite were noted in these deposits, but they form at present a small portion of the developed ore bodies. The occurrence of primary specularite intimately associated with quartz and calcite, also believed to be primary, was noted in limestones near the Little Butte property. These minerals follow roughly the stratification planes of the limestone. A notable feature of these deposits is that the usual position is in the basal limestone usually appear-

ing at or close to the underlying gneiss and overlain by amphibolitic rocks.

In discussing the origin of these deposits Bancroft first sets aside their possibility of being contact deposits. He says regarding their origin, --

"As a rule there are no intrusive rocks in the vicinity with which the deposits could be genetically connected. The association of the copper ores with specularite and their frequent occurrence between limestone and gneiss have often led mining engineers to consider them as of contact metamorphic origin, but there is no valid ground for such classification. A characteristic feature is the association with amphibolitic and chloritic rocks. As these are known to contain copper thruout, it is suggested that the metals have in some way been derived by concentration from these rocks. The formation of the deposits probably occurred in pre-Cambrian time and apparently during or after the regional metamorphism which the sedimentary series has suffered. The mineral association described is not one ordinarily occurring in regionally metamorphosed rocks, but, nevertheless, it is believed that they were found as suggested by concentration from the amphibolitic rocks during the period of dynamo-metamorphism. The association of beautifully crystallized spec-

ularite with sulphides would indicate deposition at elevated temperature and high pressure. It is also to be noted that the usual position of the deposits is in the basal limestone which generally is covered by the amphibolitic rock."

In a discussion of the genesis of these ores between A. C. Spencer and Bancroft, the role of"water of dehydration as a factor in segregating metallic ores during dynamo-metamorphism" was considered and the following suggestions arrived at.

"The well established fact that large quantities of water are set free during dynamo-metamorphism as the result of crystallization and concomitant dehydration warrants the suggestion that waters of this origin may become a controlling factor in the segregation of metallic ores. In the present case (speaking of the deposits at Signal, Planet, etc.) the original crystallization of the diabase or related rock has been destroyed and recrystallization of the constituent minerals has taken place, absorbing some of the water of dehydration by the formation of the micas, epidote, etc. The rest of the water liberated in the recrystallization could have dissolved and segregated the metallic content of the original diabase. By circulation thru intimately associated limestone strata, these waters may have been the first

agents in depositing the minerals, which thru subsequent oxidation by meteoric waters have been still further concentrated into workable deposits."

Little is known regarding the availability of the waters set free by recrystallization for segregating and depositing ores. Tho little is definitely known, the effects of dynamo-metamorphism upon the limestone and the intercalated amphibolites are believed by the author (whose views on the subject are in accord with those of W. Lindgren) to have been far-reaching and to have played a very important part in the formation of the replacement deposits of copper and iron in limestones. It is the author's belief that during the regional dynamo-metamorphism of the area the primary metallic constituents of the diabase, diorite, or gabbro which now forms amphibolite were removed, either by segregation or by the action of solutions, and were subsequently deposited in the intercalated limestones with which such deposits are invariably associated in this area.

ORE OCCURRING IN SHEAR ZONES. Carnation, Quartz King, Wardwell and Osbourne Properties, Viati Mining Company and Copper Basin Prospects. The search in the literature brot forth a type of deposit closely related to those previously described, especially to those dissemina-

tions in the amphibolitic schists, differing from the latter only in occurring in shear zones within these rocks. Ore bodies of this type occur in both amphibolitic and gneissoid rocks.

Of those occurring in amphibolitic schists those which occur at the Carnation, Wardwell and Osbourne, and Quartz King properties of Yuma County, Arizona, may be mentioned as the most important.

The rocks at the Carnation Property[1/] consist of massive limestones interbedded with amphibolitic and quartz mica schists. The deposit occurs in the amphibolitic schist and seems to occupy a shear zone or fault plane. In general the schists strike northeast-southwest and dip about 45° S. E. altho there are many local disturbances. A medium grained quartz-mica schist occurs in this series and rather complicates matters, owing to the fact that its original character is not clear. The ore deposits here seem to occupy a shear zone or fault plane in the amphibolitic schists. Ten or twelve feet above the vein occurs a thin layer of limestone, the top of which is partly replaced by hematite. Over this is a narrow band of the quartz-mica schist. The vein, which

1/ Bancroft, Howland. Loc. cit.

is 2 or 3 feet wide, consists mainly of brecciated country gangue showing some mineralization by the silicate and carbonate of copper. Post-mineral fracturing has occurred followed by a re-cementing of material by siderite, calcite and quartz, the latter forming jasper in places.

In speaking of the origin of this deposit, he says, "It is possible but hardly probable that the quartz mica schist may have been of igneous origin and intrusive in the limestone, thereby causing mineralization. The more plausible supposition is that the ore deposit was formed by concentration of the original copper content of a basic flow or of tuffaceous rocks from which amphibolite has resulted by the metamorphism of the region."

The Quartz King workings also occur in amphibolitic and chloritic schists, which strike northwest-southeast and dip nearly vertical. The veins, as observed on the upper workings appear to occupy a fault plane or shear zone which strikes S.20°-30° E. in places and north-south in general. Because of the nature of the deposits the gangue is principally sheared country rock which has been cemented in part by later deposition of quartz, showing brecciation due to subsequent movement. The ore minerals now occurring with the quartz are malachite and chrysocolla

with hematite.

The geology at the Wardwell and Osbourne property is much the same. In general the amphibolitic schists dip southwest from 10°-90° and strike northwest. The ore deposit, judging from surface exposures, occurs in a vertical fault plane which strikes S.30° W., and which is filled mainly with brecciated country rock cemented by siliceous material. The vein does not follow the planes of schistosity but cuts directly across them. The shear zone is only a few feet in width and the ore-bearing streak, as viewed on the surface, is irregular and relatively narrow.

Of those deposits occurring in shear zones in granites, gneisses, and schists, those of the Viati Mining Company property and the Copper Basin prospect may be mentioned as affording the best examples. Both occur in Yuma County, Arizona.[1/] The country rock in both properties consist of gneisses and schists presumably of pre-Cambrian age and probably resulting from the metamorphism of granites and basic diorites giving them a schistose structure of a very pronounced character, the lamination planes generally dipping to the northeast. In these deposits the gangue is chiefly brecciated country

1/ Bancroft, Howland. Loc. cit.

rock cemented by quartz and hematite, some cuprite and malachite, and with which is associated some chalcocite and an occasional speck of native copper. The ores are reported to carry some gold. Bancroft is of the opinion that these ores are of pre-Cambrian age and may be accounted for by secondary concentration of very lean primary ores which may have taken place during the dynamometamorphism of the area. Evidence of later movement is shown in the condition of the ledge.

Ore Bodies Modified by Anamorphism.

ANAMORPHOSED CONTACT DEPOSITS. The only contact deposits of this character containing copper found in the literature is the one described by W. H. Emmons.[1/] But as this deposit yields chiefly zinc and lead the description will be given under zinc and lead deposits. The ore comes from the Deer Isle mine, on Deer Isle, Maine.

ANAMORPHOSED FISSURE VEINS OF THE REPLACEMENT TYPE AND DISSEMINATED ORES ALONG FRACTURE ZONES. According to W. H. Emmons[2/] many of the so-called segregated veins of the Appalachian states are the anamor-

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1/ W. H. Emmons, Some Ore Deposits of Maine. U. S. Geol. Survey, Bull. 432; Some Regionally Metamorphosed Ore Deposits and the So-Called Segregated Veins, Econ. Geol., Vol. 4, pp. 761-2.
2/ W. H. Emmons, Econ. Geol., Vol. 4, p. 755.

phosed equivalents of presumably previously-formed fissure veins of the replacement type or of disseminated ore along fractured zones. Since most of the veins of this character occur in the eastern states, and since these deposits have been admirably described by Emmons with this idea of origin in mind, much of the material here presented will be abstracted or quoted from his article above referred to. Several later publications have appeared ~~since~~ and such new material as has been found applicable has been added.

In describing these deposits the limits of this paper prevent a description of all the many found along the Appalachians and elsewhere. Hence only typical and representative deposits will be described in full and only mention made of those that are much similar, but show slight but important differences, or bring out points bearing on origin.

Deposits at Blue Hill, Maine.[1] The deposits at Blue Hill are on the south coast east of Penobscot Bay. The mines are reported to have produced something like over 2,000,000 pounds of copper. The country rock is an

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[1] Emmons, W. H. Econ. Geol., Vol. 4, p. 759.

area of quartzites and siliceous shales and igneous rocks which have been intensely regionally metamorphosed. The pyritic copper deposits are older than the regional metamorphism and much older than the granite which is not regionally metamorphosed. The deposits are enclosed in quartz biotite schists and in schistose volcanic rocks and are oriented approximately with the schistosity. They strike eastward and dip south. They are from five to twenty feet wide and persist for several hundred feet along the strike. The central portion of the lode is as a rule composed of massive pyrite and a smaller amount of quartz. Some chalcopyrite and other sulphides are intergrown with the pyrite. Towards the walls of the deposits these slabs of schistose quartz and chlorite rock are included in the pyritic ore, and the orientation of the slabs and their constituent minerals is nearly parallel to the schistosity of the country rock. The walls themselves, which are of the same composition as the slabs, contain stringers of pyrite. There is thus a gradation from the center of the lode which is in the main massive pyrite to the country rock which carries only a little pyrite. Comb structure and druses with crustified banding are wanting.

In the Twin Lead mine[1/] located about 1050 feet

1/ Emmons, W. H. Some Ore Deposits in Maine. U. S. Geol. Survey, Bull. 432, p. 32.

east of the Blue Hill, the ore minerals are pyrite, pyrrhotite, magnetite, chalcopyrite, and a little bornite. The gangue minerals are quartz, sericite, biotite and chlorite. The pyrite is disseminated thru the rock and in bands parallel to the schistosity, but lenses of ore consisting mainly of pyrite, chalcopyrite and quartz are found here and there in the lode. A stringer of pyrite making off from the main lode shows that the quartz and pyrite are older than the metamorphism of the schist, a fact also indicated by the arrangement of the minerals in the low-grade ore.

At the Steward Mine[1/] the country rock is also the Ellsworth schist, and contains here considerable biotite, but is also more siliceous than at Blue Hill and Twin Lead. Actinolite, tremolite, biotite, sericite, chlorite, and zircon are microscopically visible, Near the lode the quartzose schist carries considerable pyrite and some chalcopyrite, magnetite and pyrrhotite. The trend of the deposit is the same as the schistosity and the pyrite bands are crumpled like the silicates, showing that the ore was deposited before the regional metamorphism of the country.

Among the other deposits around Blue Hill those of

1/ Emmons, W. H. Loc. cit,,p. 33.

the Douglas, Mammoth, Owen, Granger, and Weil Freddie mines may be mentioned. They differ in no respects from those already described.

Tapley Mine, Maine.[1] The Tapley mine occurs about 2½ miles southwest of Brooksville. The country rock is in the Castine formation, which is here, in the main, a rhyolitic breccia, but which locally includes a dark rock, presumably andesite. Both of these rocks are regionally metamorphosed, with the development of secondary biotite, sericite, and tremolite. The schistosity of the rock, which tho not pronounced, is well defined, and strike northeastward. The lode strikes parallel to the schistosity, and is a wide zone of shattered and altered rhyolite. The sulphides are pyrite, and chalcopyrite, both of which are found at the very surface with little surface alteration. The ore includes fragments of the country rock which are slightly silicified, but the lumps of pyrite ore on the dump contain but little quartz. These fragments contain much more sericite and chlorite than the country rock a few feet from the vein. Some of the ore impregnated with pyrite shows laminated sericite and quartz, and some of the chalcopyrite is feebly laminated

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[1] Emmons, W. H. Loc. cit., pp. 35-6.

parallel to the micaceous sheen which shows when the ore is held in a suitable position, suggesting that the sulphides were found before the regional metamorphósing processes had ceased operation. The relationship is also indicated by the crumpled stringers of pyrite which are found near the lode. Deposits of a somewhat similar nature occur at the Eggemoggin, Cape Rozier, Hercules, Jones and Dodge, and Emerson Mines, all in the state of Maine.

Milan Mine, New Hampshire.[1] The Milan Mine is located in Coos County, northern New Hampshire. The deposit was discovered in the seventies and was worked steadily till 1886 with a monthly production of 2600 tons, which was presumably sustained for several years. The mine is producing steadily at the present time.

The country rock at the mine is a highly metamorphosed siliceous schist. It has well defined planes of schistosity which near the mine strike northward and dip westward from 30° to 90°. Altho no quartzites, limestones, or conglomerate layers, or grains of grit, bedding planes or other characteristics of sedimentary rocks are found to show its clastic character, the mineralogy of the wall rock is such as may have resulted from the intense regional

[1] Emmons, W. H. Loc. cit., p. 762.

metamorphism of a quartz-rich shale or clayey quartzite, and there is nothing in its general appearance and mineralogical composition which is inconsistent with a sedimentary origin. The rock as it now appears may be called a quartz-biotite schist. On the 115-foot level of the mine about 35 feet northeast of the shaft, there is about 3 feet of an actinolitic schist which is different from the quartz-biotite schist of the wall rock in that it appears to be more basic, and to judge from its relations with the schist it is probably the metamorphosed product of a dike of diabasic or more acidic composition -- one that cut the siliceous country rock before it was metamorphosed. The ore bodies are two overlapping pyritic lenses separated by 10 or 15 feet of biotite schist and striking a few degrees east of north and dipping steeply westward parallel to the schistosity of the country rock. They are not tabular in form, but broadly approaching that form, altho in detail they are characterized by gentle undulation both along dip and strike. The gangue consists of quartz, chlorite, black and white mica, the sulphides of pyrite, chalcopyrite, zinc blende, galena, bornite, and chalcocite.

The relationship of the ore and gangue is the important feature illustrated by this mine. The ore bodies

are parallel to the schistosity. At some places the walls are intensely crumpled and much of the milling ore consists of thin alternating bands of schist and pyrite intimately interbanded and crenulated. The seams of pyrite and quartz are parallel to the schistosity of the country rock, and, according to Emmons,believed to be clearly metamorphosed by the same crumpling movements, and the ore is thot to be undoubtedly older than the metamorphism of the schists. At many places it grades into the pure massive pyrite ore but the latter does not show any schistosity. Emmons found no noticeable sericitization or other hydrothermal alteration of the walls or any leaching of the wall rocks, such as is characteristic of most ore bodies not regionally metamorphosed and the ore at no place showed comb structure, crustification or druses.

The plan of the ore body on the 115-foot level illustrates further the effects on the ore body of the regional metamorphism due to intense shearing movements under load, which developed the schistose structure in the country rock. Before shearing the ore body was probably a single tabular mass, but by these movements was thrust endwise upon itself so that it divided and overlapped. The division or fault took place in the zone of flow for

the schist and shows that the ore must have been deposited before the last regional metamorphism of the country. This is further indicated by the gradation of the massive pyrite ore to pyrite containing parallel quartz and mica bands, to quartz-biotite with numerous thin bands of pyrite, and this into schist with only an occasional band of pyrite to nearly pure schist. The main lode of pyrite ore has exactly the same character as the smaller massive layers and must have the same origin, but where pure and large it is as free from conspicuous marks denoting movement as any ore deposit in unmetamorphosed rock. The pure pyrite is at no places laminated. The larger bodies have broken and have been cemented by pyrite or chalcopyrite and the smaller crystals have completely crystallized. Galena and zinc blende have also recrystallized, but some of the chalcopyrite shows faint laminations.

At the place where the ore body pulled apart Emmons notes that the ore is highly siliceous and consists of intensely crumpled pyrite and quartz, and looks much like gnarled oak or mermicelli. This shows that the movement was best recorded where there was an heterogeneity of composition. If it had been pure pyrite instead of quartz-pyrite-chlorite ore it would not have shown the intense crumpling for the pyrite would have broken and recemented into an apparently homogeneous mass.

Regarding the mode of genesis of this deposit, Emmons believes them to be large masses of ore contained in impure quartzites and genetically connected either with the "lake and granitic gneiss" or with the basic igneous rock which now appears as the actinolitic schist. He presumes that the deposit was first formed at moderate depth, and consisted of quartz, pyrite, zinc blende, galena, and chalcopyrite, with some aluminous material -- either clay or sericite. The walls near the vein were presumably replaced by pyrite and other minerals. It was deeply buried after deposition for it is found to be intensely deformed in the zone of flow at the time when the siliceous shales were subjected to regional metamorphism and changed to schists, or at least before the process had ceased to operate. The ore body was pulled apart where most siliceous, where parallel sheets of quartz and mica were abundant in mica, and because of this heterogeneity, a maximum of squeezing and crumpling was recorded. The sulphides were crushed, recemented, and at some places dissolved and re-precipitated. Drusy cavities, banded and comb structures, if present, were destroyed as well as many evidence of hydrothermal metamorphism along the walls of the deposits.

Ely Mine, Vermont.[1/] The Ely mine was at one time one of the largest producers of the country, but the mine is now idle or has an insignificant output. The country rock is a biotite schist greatly folded and cut by granite. The ore minerals are pyrrhotite, chalcopyrite, some pyrite and zinc blende. The deposits are parallel to the schistosity. According to Weed[2/] the ore forms lenses which overlap, and on going down where one plays out the tapering body of another lens overlies the lower end of the upper body. Along the strike the ore may end in a blunt wedge, may fork in thinning wedges, or grade into the country rock by increasing "slaty" material. The ore bodies at the Elizabeth mine are from 35 to 100 feet wide; at the Ely the overlapping lenses continue for 3,400 feet to the bottom of the flatly inclined shaft.

With respect to the genesis of these deposits we have the authority of H. L. Smyth and P. S. Smith[2/] that they were deposited since the metamorphism of the country. A photograph of the Ely ore shows the sulphides are concentrated in the axes of crumpling of the saddle and trough of the minute anticlines and syncline of the crenulated

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1/ Emmons, W. H. Econ. Geol., Vol. 4, p. 769.

2/ Cited by Emmons. Econ. Geol., Vol. 4, p. 769.

schist, which corresponds somewhat to the ore of the Milan Mine of New Hampshire. In the Milan ore, Emmons believes that the ore collected in the minute anticlines and synclines, not because they were open spaces, but because they were places of least pressure. Apparently Emmons does not hold that the chief mineralization occurred at the time of the Barre granite intrusion, for he says that the ore deposits associated with those of Maine are of silver, lead, and molybdenum with never more than a very small amount of chalcopyrite. He states that the granite at the Elizabeth Mine is replaced by ore, and that there must have been some mineralization, or at least rearrangement of minerals as a result of the intrusion. Continuing he says, "If the chief mineralization occurred at that time, the deposit is unique in New England and would have a closer genetic connection with certain gold deposits of the southern Appalachians." On the other hand, he calls attention to the overlapping character of the lenses of ore at the various mines, stating that this is characteristic of regionally metamorphosed deposits, and he also calls attention to the fact that elsewhere the unmetamorphosed granites of northern New England were not magmas rich in copper.

Davis Mine, Franklin County, Mass.[1] The mine yields a firm crystalline pyrite, with a little chalcopyrite, and

1/ Weed, W. H. U. S. Geol. Survey, Bull. 455, p. 33.

has an output of about 400 tons of mineral a day. The deposit occurs in the Hawley schist, a formation of Ordovician age, composed mainly of sericite schist with intrusive bands of amphibolite. The belt of the Hawley schist carries lenticular beds and impregnations of pyrite, but of these the Davis is the only continuous producer. The Davis pyrite deposit is a great lens, 6 feet to 24 feet thick, that lies intercalated between sericite schist on the west and chlorite schist on the east. The deposit has a strike of N. 30° E. and a dip of 70° E., both conforming closely to that of the inclosing rock. The deposit consists of coarsely granular pyrite, with some admixed chalcopyrite, blende, garnet, and galenite, the last two named being rare.

Virgilina District, Virginia.[1] Several peculiar features of this deposit lead W. H. Emmons to believe that regional metamorphism has had much to do in its formation despite the views of W. H. Weed.[2]

The country rock is schist and gneiss which are regarded as of igneous origin. They include andesite,

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[1] Emmons, W. H. Econ. Geol., Vol. 4, p. 772.

[2] Weed, W. H. U. S. Geol. Survey, Bull. 455, pp. 65-93.

and altered andesitic tuffs and are cut by dikes of diabase. The veins are lenses connected by strings of quartz which strike N. 5°-10° E. and are arranged with overlapping ends. Some are parallel to the schistosity and some cross it. Commonly the quartz is incased in shells of micaceous schist and many thin films of schist are included. Neglecting the oxides, the principal minerals are quartz, calcite, epidote, pyrite, chalcopyrite, chalcocite, bornite, and gray copper. Banding is common, but is due to included schist.

These veins are regarded by W. H. Weed as having been deposited in openings in the schist and later than the metamorphism of the country, but Emmons notes in his descriptions the lack of any record of crustification, vugs, or druses which should be expected in such deposits. His description of the streaked or ribboned appearance is not due to crustification or to recent movements of the vein, but to partly replaced sheets of slate.

Emmons quotes L. C. Graton, who in Mineral Resources for 1907 (page 620), states that the chalcocite in these veins is primary . The former has also seen some of the ore from Virgilina and states that it differs from the common type of chalcocite in that it has none of the common secondary structures and seemed to be from a

vein too tight to have been derived from descending solutions. The genesis of this is important, as it appears to be the first occurrence of primary chalcocite, and if it can be formed by ascending thermal solutions this fact should be generally recognized. Apparently this view is not held by Emmons, who in closing his description of the Virgilina ore says, "The hypothesis that the ores are in part regionally metamorphosed secondary sulphides is attractive since it explains some puzzling features of the deposits."

<u>The Ore Knob Mine, North Carolina</u>.[1/] Large quantities of copper have been taken from this type of deposit especially in the days before the war. The country rock belongs to the series of schists and gneisses called by Keith the Carolina gneiss. In general the rocks of the region are thinnly foliated gray gneisses often schistose when weathered. The vein has been traced by means of shafts for about 1½ miles, and has a course of N. 65° E. which nearly parallels that of the schistosity which is N. 57° E. The dip of the vein is, however, nearly perpendicular to that of the schistosity which is 40°-45° S.E.

1/ Emmons, W. H. Econ. Geol., Vol. 4, p. 773.

The ore body consists of pyrrhotite, with a little pyrite and chalcopyrite. It is mainly massive and contains much quartz.

Gold Hill Deposits, North Carolina.[1] The deposits occur 14 miles southwest of Salisbury, North Carolina on the Piedmont Plateau. The rocks are much weathered, but consist of a rock which varies from a hard and dense siliceous gneiss to soft talcose material. The auriferous quartz veins so far as the writer, W. H. Weed,[1] has observed, conform in dip and strike to the secondary schists. They show no banding and are composed largely of a distinctly and finely granular dark gray quartz, with patches, spots, and streaks of ore. They present little or no crystalline or massive white or transparent quartz such as is commonly seen in quartz veins, and is usual in the auriferous "stringer" lodes of the South. The ore below the water level consists of pyrite, chalcopyrite, and quartz with occasional bunches of galena and blende. The pyrite is in broken, shattered masses, in part cemented by chalcopyrite, which is distinctly later. The extreme upper part of the vein is barren of copper, but has been

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1/ W. H. Weed. U. S. Geol. Survey, Bull. 455, pp. 141-144.

worked for the gold.

According to Weed[1] the ore is a breccia of silicified schist, and that the schist was presumably metamorphosed before the ores were deposited. Emmons in reply to this again calls attention to the fact that there is no banding or crustification, but also recognizes the fact that regional metamorphism of a later and milder type may have obscured these traces. In general, however, they seem to correspond in the general features with those previously described.

Seminole Copper Deposits of Georgia.[2] The country rock is a quartz-rich biotite sericite schist, which like the ore is cut by many schistose dikes composed of feldspar, hornblende, biotite and much quartz. A more acid igneous rock also occurs near the deposit. The ore is composed of chalcopyrite, galena, sphalerite, ~~and~~ pyrite and alteration products, and carries gold and silver. The lodes are possibly a few degrees off the schistosity. Of the ores Watson[3] says:

1/ Cited by Emmons, Econ. Geol., Vol. 4, p. 773.

2/ Emmons, W. H. Econ. Geol., Vol. 4, p. 774.

3/ Cited by Emmons, from U. S. Geol. Survey, Bull. 225, pp. 182-187.

"Like the country rock proper, they are thruout thinnly laminated or schistose in structure. The ore is distributed thru the veins in the form of stringers, irregular bunches, or nests, and as large and small disseminated grains and particles. The ore occurrence as disseminated grains or particles, closely resembles that of the enclosing rock, except that in the veins the mineral particles are in a more localized and concentrated form. The ore distributed thruout the surrounding rock, particularly the pyrite, is invariably in the form of large and small cubical crystals. The central portions of the vein are characteristic and are sharply differentiated from the inclosing rock, while the outer portions next to the wall appear less easy of differentiation from the schists in many places. Lenses of varying size, composed of schists similarly silicified and mineralized as true veins,occur between the veins and in some instances afford equally as good ore. These lenses may be spaced at wide intervals or they may occur close together."

Of the genesis Watson says: "From available field evidence the order of events, so far as it has been possible to interpret them, are in general, as follows: An early period of intense dynamic disturbance caused by extensive crushing and fracturing of the country rocks,re-

sulting in secondary structure. This was followed by silicification and mineralization concentrated along fairly well defined, roughly parallel lines marking the present veins, A second period of disturbance resulted in the intrusion of the rocks of basic igneous dikes. Finally, there was a third period of dynamic action, which rendered the massive dikes schistose in structure and caused further mineralogical alteration of the dikes into forms unlike the original eruptives. Necessarily the second and last period of disturbance increased the metamorphism of the country rock and aided in the mineralization."

Since the ore is cut by schistose dikes, it is certainly a regionally metamorphosed deposit. It is to be noted that the description of the central portion and edges of the lode correspond almost exactly with those given by Emmons for some of the deposits of northern New England.

Ducktown Deposits, Tennessee.[1] Commercially they are by far the most important copper deposits of the Appalachian states, having produced up to the close of 1911 approximately 230,660,000[2] pounds of copper. The output

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[1] Emmons, W. H. and Laney, F. B. U. S. Geol. Survey, Bull. 470, p. 151.

[2] Mineral Resources, 1911, part I, p. 301.

for 1911 was 18,965,143 pounds. The ore bodies occur in the highly metamorphosed Cambrian sediments and the inclosing rocks are quartz mica schist. In the main the ore deposits are roughly tabular. Some of them are lens-shaped and most of them are in places curved. All are included in metamorphosed sedimentary rocks and, except where faulting or close folding is apparent, the beds are parallel to the contacts of the ore and country rock.

The primary ore consists of pyrrhotite, pyrite, chalcopyrite, zinc blende, bornite, specularite, magnetite, actinolite, calcite, tremolite, quartz, pyroxene, garnet, zoisite, chlorite, micas, graphite, titanite, and feldspar. The minerals are generally intergrown and of contemporaneous age. Essentially the same minerals are found in all the deposits, but they appear in varying proportions at different places in the lode. The lodes have an average thickness of 50-75 feet. Some of the layers of sandy schist included in the ore are believed to represent beds that were deposited with the limestones. The ore minerals are not arranged in layers or crusts one upon the other, like minerals deposited from solution in an open cavity, but are intergrown and are assumed to have formed at the same time. At some places the silicates inclose the sulphides, at others,

the sulphides inclose the silicates, and at still others the two are intimately intergrown so that neither set of minerals may be said to inclose the other.

The ore zones have been clearly folded and in some places a thickening on the crest is conspicuous, altho all crests do not show this feature. Faults cut the ore bodies, but they usually follow the strike so that they can not be accurately shown owing to the lack of definite horizon markers.

Opinion as to genesis varies considerably.

J. Sterry Hunt[1] regarded the deposits as filling rifts and fissures. According to Carl Henrich[2] they are replacements of dikes of pyroxene rocks which cut across the schistosity along fault fissures. J. F. Kemp[3] regarded them as the filling of a series of dislocations along the lines of the present veins. W. H. Weed, as cited by Emmons in Economic Geology, Volume 4, page 775, is thot to have considered them as replacement veins, but in his bulletin on the "Copper Deposits of the Appalachian States" it appears that he has changed his views, for

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1/ T. A. I. M. E., Vol. II, p. 124.

2/ T. A. I. M. E., Vol. XXV, p. 173.

3/ Ore Deposits of United States and Canada, 1906, p. 192.

on page 153 he says, "The structural characters of these ore beds show that they fill fault fissures, which follow the foliation and correspond to slip planes between the "beds". This movement probably furnished a channel for ore-depositing waters. The ore body has been modified by faults since the formation of the vein, to which the present lenticular forms of the ore bodies are perhaps partly due. The ore body is thrown by these faults, and the schistose structure may be due to this and not to original replacement".

Emmons has studied these deposits in 1910 and the results of his investigations appear in a preliminary report previously cited. The conclusions of his genesis of the primary ores will be given and appear to be that he regards them as replacement deposits of limestone beds originally associated with the sedimentaries, and that the replacement was probably by magmatic waters.

The present form in which these deposits now occur is important for it is this fact that admits of its classification as a regionally metamorphosed deposit of the replacement type. Regarding this feature Emmons[1/] says:

"The forms of the ore bodies and their relations

1/ Emmons, W. H. Ducktown Ore Deposits. U. S. Geol. Survey, Bull. 470, p. 168.

to the other beds show that the rock ~~with~~ which the ores ~~are~~ replaced, or the ore bodies themselves, have been involved in all the deformation by dynamic metamorphism to which the country rock has been subjected. The major portion of the dynamic metamorphism, resulting in the development of slaty cleavage and close folding of the beds, may have taken place before mineralization, but some deformation has taken place since the ores were deposited. The gangue minerals which are included in the sulphides are generally broken and crushed, and in some thin sections of the ore the pyrrhotite shows minute crinkling of closely space planes. Pyroxene and zoisite crystals are bent and twisted. At many places the ore appears brecciated and small balls consisting predominantly of actinolite, garnet, and quartz with a subordinate amount of sulphides are surrounded by heavy sulphide ore containing numerous broken fragments of hornblende. In the No. 20 mine some of these balls are elongated ellipsoids. At some places the minerals of the gangue are oriented in parallel layers, like the minerals of a schist, but in general the gangue of the ores is not schistose. Recrystallization, following deformation, may have obscured certain metamorphic structures. Little is known regarding the behavior of metallic ores in

differential stresses, under a heavy load, and the data are insufficient to warrant a statement regarding the degree of the deformation of the ores or the depth at which they were formed."

Discussion of the Anamorphosed Fissure Veins of Replacement Type and Disseminated Ores along Fracture Zones. The space of this paper prohibits a further description of the deposits of this type, as too many occur thruout the Appalachian states and elsewhere in metamorphosed sediments in which the so-called segregated veins are found. Enough have been described, it is believed, to give the reader a fair idea of the type and their treatment will be closed with a general summing-up statement of this type of deposits, giving their occurrence, physical and chemical changes involved in their formation, and some views as to their origin.

Summary of Occurrence.[1] The deposits are found nearly everywhere in a belt of old rocks intensely dynamometamorphosed. They are enclosed in schists of various kinds - quartz schists, mica schists, chlorite schists,

[1] W. H. Emmons. Op. cit., p. 756.

chlorite-biotite schists and actinolite schists. The ore bodies are oriented parallel or nearly parallel to the schistosity and at many places the ore bodies are lenses which in a single mine are parallel and usually overlapping. The lodes are from one to one hundred feet wide and many of them persist along the strike for several hundred feet. The most abundant ore minerals are pyrite, pyrrhotite, and chalcopyrite, but galena, zinc blende, arsenopyrite, bornite, tetrahedrite and stibnite are found in many of these deposits. Some gold and silver are usually present. The copper-bearing oxides and secondary sulphides are often developed near the surface. The gangue minerals include chlorite, biotite, muscovite, epidote, quartz, calcite, garnet, tremolite, actinolite, and zoisite, but all of these are not present in each deposit. There seems to be no evidence of hydrothermal alteration of the wall rock of the same character which is common in the younger deposits of the western states.

Physical Changes Involved in Their Formation.

In discussing the physical changes Emmons[1/] notes that the metamorphosed ore deposits are in the main parallel to the

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1/ Emmons, W. H. Econ. Geol., Vol. 4, p. 776.

schistosity of the country rock, or else cross it at small angles and this is thot to be in accord with the law that under stress in the zone of flow tabular bodies will tend to orient themselves in the direction of least pressure,or right angles to the direction of greatest pressure. A comparison is drawn with the quartz particles which are relatively short in one direction and which will revolve and orient themselves with their longer dimension in the direction of least pressure. The large tabular bodies of sulphide are not believed to move so freely, but evidently the same mechanical processes operated on them. Some of them are broken in the process which gives rise to the parallel lenses which nearly everywhere are overlapping.

The deposits considered are believed to have been in part replacement veins and if so, such phenomena as crustification and symmetrically-lined druses may never have been developed. If these structures were present, they have been destroyed by regional metamorphism.

The great width in comparison to their length is another characteristic feature of these regionally metamorphosed deposits, and is in part thot to be explained by the possibility that some of them have become thicker by reverse faulting. Probably a large number of the

deposits have been flattened out to masses too thin to justify development and that these have been overlooked while the larger deposits only have attracted attention, giving an erroneous idea of their common shape.

Chemical Changes Involved in Their Formation.[1/] Under deep-seated conditions as shown by Van Hise[2/] and Leith[3/] the minerals are dissolved and are re-precipitated to form new minerals which are more stable under the new conditions of pressure. The medium thru which the changes are carried on may be the small amount of water trapped in the buried rock. The minerals formed under pressure are in part the heavy anhydrous compounds such as garnet, staurolite, etc., but certain hydrous silicates, such as chlorite, muscovite and biotite are more extensively found. The mineral changes are great, but deep in the zone of flow the chemical changes are mainly those of solution and re-precipitation and the water thru which these changes are brot about, ~~are~~ probably moves in a restricted sphere, except that which gradually escapes to the surface with the CO_2 and other salts.

1/ Cited by W. H. Emmons, Econ. Geol., Vol. 4, p. 777.

2/ Op. cit.

3/ Emmons, W. H. Econ. Geol., Vol. 4., p. 777.

As E. S. Bastin[1] believes the mineralogical changes in the deep-seated alteration of sediments are due to a rearrangement of the elements therein contained and not to the introduction of new elements, so Emmons holds that the processes which operate in the regional or dynamo-metamorphism of the ore bodies, are solution and re-precipitation, mashing and cementation, the elements being rearranged within the ore body, but little or nothing being added. The dissolving power of the included water is increased by heat supposedly generated by friction, and precipitation is accomplished upon cooling after the stresses are relieved.

Emmons calls attention to the fact that chalcopyrite cements the broken pyrite crystals at the Blue Hill, Milan, and Ducktown deposits and states that this feature is possibly characteristic of these deposits as a group. Concerning this feature he says, "some of this chalcopyrite is not connected with any vein which might fill a fissure, leading to an outside source, and I believe that such chalcopyrite is merely the copper, iron, and sulphur which were dissolved and re-precipitated just as pyrite was dissolved and re-precipitated. If so, then the cop-

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[1] Cited by Emmons, W. H. Econ. Geol., Vol. 4, p. 778.

per iron sulphide is more soluble under conditions of regional metamorphism than the iron sulphide."

Continuing, he states that according to Weigel[1/] 70.1×10^{-6} mols of freshly precipitated FeS is dissolved in a liter of pure water at room temperatures and pressures while only 3.51×10^{-6} mols of CuS is so dissolved, and he suggests that possibly a mixture of the two $CuFeS_2$ (chalcopyrite) would be more soluble than the salt alone and would be precipitated last and in the cracks of the pyrite.

Hydrothermal alteration of the wall rock should accompany these deposits if they are metamorphosed equivalents of primary ores. Sericitization, which is the commonest type of such metamorphism, is suggested in the deposits of Maine and New Hampshire where chlorite, biotite and sericite are developed in the wall rock, but these are also developed in the country far away from the veins, tho possibly not so abundantly. This is especially true of the deposits at Blue Hill, Maine.

1/ Cited by Emmons, W. H. Econ. Geol., Vol. 4, p. 779.

Origin of These Deposits. The origin of the so-called segregated vein deposits has been much discussed, but there are many features of their history which are still in doubt. J. D. Whitney,[1] as early as 1854, applied to them the term "segregated veins."

C. Hitchcock[1] in 1878 described the deposits of Gardner Mountain, Grafton County, and the Milan Mine, New Hampshire, and gave the following summary of their genesis.

"Our theory as to the origin of the deposits has been that they were originally beds not fissure veins, and that in later periods the copper has been segregated from the general metalliferous belt into several stringers and veins making up the richest portions. I have thot the continuity of the vein is to be seen in the presence of a series of lenticular patches or bonanzas not succeeding each other on absolutely the same plane but overlapping."

Robert Hunt[1] states that "the segregation veins may be considered ~~as~~ contemporaneous or may be produced during the infiltration of solutions after the rock has partly consolidated either by the action of heat or the

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[1] Cited by W. H. Emmons. Econ. Geol., Vol. 4, p. 757.

influence of time."

J. F. Kemp[1] in the 1906 edition of "Ore Deposits of the United States and Canada", describes a number of these deposits. In his summary of the Ducktown deposits he states that in his opinion after the general metamorphism, a series of dislocations was developed along the lines of the present veins, and pyrrhotite and sometimes pyrite were introduced.

W. H. Weed[2] says of certain segregated deposits in basic rocks:

"The minute copper contents of diabase and diorite are sometimes segregated by solution at the same time and as part of the process of metamorphism which transforms the igneous rocks into amphibolite."

R. S. Tarr[3] regarded them as the result of dynamo-metamorphism and concentration of material from surrounding rocks, pre-existing cavities not being necessary.

Waldemar Lindgren[3] says of his use of the term "segregated vein": "I have used it as meaning more or less lenticular openings in the mass of slates and schists parallel to the strike and dip, produced by longitudinal compression and filled by a sort of lateral secretion or

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1/ Cited by W. H. Emmons, Econ. Geol., Vol. 4, pp.757 & 775.
2/ Cited by W. H. Emmons, Econ. Geol., Vol. 4, p. 758.
3/ Bull. Geol. Soc. of Am., Vol. 16, pp. 221-240.

exudation from the surrounding rock."

Emmons[1/] believes that at least a number of the segregated veins so-called are regionally metamorphosed deposits which at one time were presumably fissure veins of the replacement type. He recognizes the difficulties inherent in the problem of their genesis. He says concerning this point. --

"The center of the lode is often massive sulphides which appear in all respects like any unmetamorphosed sulphide deposit in the younger rocks of the West. In hand specimens it shows no signs of schistosity or lamination, but along the margins of the deposit where portions of the country rock are involved with the sulphides, thin pyrite bands and quartz bands alternate with the bands of schist and are all crumpled together. Bands of pyrite intensely crenulated may make out into the country rock. The relations too may further be obscured by post-mineral planes of fracturing or slickensliding near the walls. Because of these features some observers have regarded the massive ore near the center of the lode as a later introduction in the older crumpled bands of iron sulphides and country rock, but when one attempts to map

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1/ Emmons, W. H. Econ. Geol., Vol. 4, p. 758.

ore of two generations he is forced to conclude that it is all of the same age, for the massive pyrite and the schistose rock with crumpled pyrite bands show every stage of gradation one into the other."

In discussing the metamorphism of these deposits he says:[1]

"The behavior of the sulphides during regional metamorphism is noteworthy. Where the ore is nearly pure sulphide, composed of pyrite with some chalcopyrite, it is crushed and recemented by pyrite or chalcopyrite. It then appears massive and shows little or no schistosity, and one examining the central part of the lode would not suppose that it had been deformed with the metamorphism of the schists. But near the walls, in the lower grade ore composed of pyrite, quartz, chlorite, and mica there is a well-defined schistosity. From microscopic studies it is seen that some of the crushed fragments of pyrite have oriented themselves parallel to the schistosity between the grains of quartz. The crushing is especially well shown where two crystals of pyrite are pressed against each other or against a grain of quartz. If the pyrite crystals are surrounded by chlorite or by mica,

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[1] Emmons, W. H. U. S. Geol. Survey, Bull. 432, pp. 18-19.

they are protected by these yielding minerals, but where two pyrite crystals touch they are shattered and recement-ed. Some perfect crystals of pyrite are formed, however, from iron sulphide dissolved and reprecipitated; such are found mainly in thin crumpled seams where movement has been most intense. Under these conditions cubes and octahedra are developed rather than pyritohedra or pentagonal dodecahedra. The pyrite was deposited in perfect crystals even under conditions of great pressure and the presence of other minerals."

"It is no easy task", he continues, "to determine the character of these deposits before they were metamorphosed, but this may be inferred from their present condition and mineralogical character. The diagnostic value of the minerals is lessened by the fact that nearly all of them may be produced under conditions of regional metamorphism wherever the necessary elements are at hand."

Production and Reserves of Copper Deposits.

No ores have as yet been produced from the type of ore occurring as disseminations in amphibolitic schists and supposed to have been formed as a result of anamorphism. Of these, those of the Encampment district of Wyoming and those in Colorado give some promise of production in the future.

Ores belonging to the same general class with the above, but occurring as replacement of limestones, have made a somewhat better showing. The Planet property up to 1877, according to H. C. Hodge, has produced 8,000 tons of copper ore, which were shipped to San Francisco. Railroad facilities will greatly increase the output as the ore had to be hauled by wagon to the Colorado River. The Little Butte property has produced 22 cars of ore yielding 7.6% of copper, 28.9% iron, 2.4 oz. of silver, and $6.65 in gold per ton. No production from the Signal property was reported. All are in the development stage and judging from the descriptions of the equipments installed, good ore in sufficient quantities seems warranted.

From the ores occurring in shear zones little can be predicted in the way of future production, as many of the prospects described were idle at the time of the

author's visit to these places. Only a very small production is reported from the Copper Basin prospect.

Ore bodies modified by anamorphism have also produced only small amounts of the total production of copper. The anamorphosed contact deposits of Deer Isle Mine of Maine have since 1907 produced only about 900 tons of ore. The anamorphosed equivalents of fissure veins of the replacement type and disseminated ores along fracture zones show somewhat better results. The deposits at Blue Hill have produced something over 2,000,000 pounds of copper. The Milan Mine was discovered in the seventies and was worked steadily until 1886. According to H. J. Davis[1/] the monthly production was 2,600 tons, and this production was presumably sustained for several years. The property was closed on account of the fumes of the smelter, but was opened again in 1895 when about 1500 tons of ore were mined. Emmons states that the Milan Mining and Milling Company are now working the mine and making regular shipments of ore and concentrates.

The production of the Ely mine of Vermont has fluctuated. From 1854 to 1866 7,942 tons were shipped.

1/ Mineral Resources of the United States for 1885, U. S. Geol. Survey, 1886, p. 501.

Copper produced in 1876 was 1,646,850 pounds; in 1880, 3,186,175 pounds; and in 1890, 7,500,000 pounds.

No figures are given for the deposits at the Davis Mine , Massachusetts, the Virgilina district of Virginia, the Ore Knob and Gold Hill deposits of North Carolina, and the Seminole copper deposits of Georgia. Many of these and similar ores will be worked in the near future for their copper and gold contents. The Gold Hill yielded in 14 years some $12,000,000 in gold and contains much more associated with the sulphides.

The Ducktown deposits of Tennessee constitute the chief production from the type of ore deposits modified by anamorphism, having produced from 1845 to 1911 some 230,600,000 pounds of copper. In 1911 Tennessee ranked eighth in the production of copper for the United States, producing about 1.72% of the total, or 18,850,276 pounds of copper.

ZINC AND LEAD.

General Statement.

Search thru the literature revealed a description of the anamorphosed equivalent of a contact deposit and the anamorphosed equivalent of an ore body whose exact original mode of origin is not definitely known. The first is not important commercially, but is from the genetic standpoint. The latter constitutes the zinc and manganese ores of Franklin Furnace district of New Jersey and are important commercially, constituting one of our chief sources of zinc and manganese.

Anamorphosed Contact Deposit.

The deposit at Deer Isle, Maine[1 & 2] was mentioned under copper, but since according to G. H. Holden the high grade ore carries 30% of zinc, 16% of lead and only 2½% of copper, it was thot best to reserve the description until now.

The Deer Isle Mine is located at tide water on

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[1] Emmons, W. H., Some Regionally Metamorphosed Ore Deposits and the So-called Segregated Veins. Econ. Geol., Vol. 4, pp. 761-2.

[2] Emmons, W. H., Some Ore Deposits of Maine. U. S. Geol. Survey, Bull. 432, p. 37.

Dunham Point about 3 miles west of Deer Isle village, Maine. The mine was first opened in the seventies, and was reopened in 1907, since which it has produced about 900 tons of ore.

The mine is in the Castin formation, presumably an altered porphyritic rock with phases which were probably calcareous water-laid tuff. The North Haven greenstone, regarded by Smith, Bastin and Brown[1] as of the same age as the Castin, outcrops nearby.

The lode follows the schistosity of the country rock, striking from N. 22° E. to N. 70° E., and dips from 45°-55° N. It is composed of sheets of pure sulphide an inch or two wide, which persist for several feet along the dip and strike and are overlapped by similar sheets. The rock between these is composed of innumerable paper-thin plates of alternating sulphides and garnets. The sulphides are steel-colored zinc blende, pyrite, galena and chalcopyrite. Intergrown with them is a considerable amount of magnetite. The gangue minerals are garnet, actinolite, sericite, calcite, chlorite, quartz, barite and rhodochrosite. Without doubt, Emmons believes the deposit to have been regionally metamorphosed since it was formed,

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1/ Smith, Bastin, and Brown. Geol. Atlas of U. S., Folio #149, p. 5.

and the high schistose structure of the lode which parallels that of the country rock has resulted from the same dynamic forces which developed the schistosity of the country rock. The minerals are similar to those of contact metamorphic deposits, but they have been rearranged by regional metamorphism.

The sulphides have been crushed, recemented and in part recrystallized. The chlorite and mica seem to have been completely dissolved and recrystallized with their longer axes parallel to the schistosity and to the orientation of the lode. The garnet is so highly fractured that in places it is almost opaque in thin sections. None of the garnet shows crystal form.

Emmons compares the garnet here found with other occurrences. He says, "garnet, as is well known, is formed in igneous rocks in contact metamorphic deposits, in some veins of the deep zone and by regional metamorphism. In igneous rocks it is nearly always idiomorphic. In contact metamorphic deposits it is either massive or idiomorphic and very often shows such optical anomalies as double refracting rings. It may appear to have the schistose structure where it replaces schists in contact metamorphic deposits, but it is not highly cracked and some of the garnets usually have the crystal outline or

else show the double refracting rings. In veins of the deep zone it is usually idiomorphic. The garnet of the Deer Isle mine is not idiomorphic. The garnet is so highly crushed that it lets thru very little transmitted light and is, therefore, nearly dark where the nicols are not crossed. Under the microscope it has the color and general appearance of andradite, and without much doubt is contact metamorphic garnet which has been regionally metamorphosed."

To prove that the garnet and tremolite were not developed by prodesses of regional metamorphism when the ore bodies were subjected to the stresses which developed its schistosity, the author shows that the garnet does not occur in perfect crystals which usually form under such conditions, but in crumpled bands mashed and highly fractured, alternating with other minerals. Further, he cites that garnet and actinolite are rare or absent in the Blue Hill copper deposits, which with respect to regional metamorphism have a similar history.

Anamorphosed Ore Body, - but Original Character Unknown.

Franklin Furnace District, New Jersey.[1] These ore bodies are located in the recrystallized white limestone which lies next to the gneiss on the northwest. Both are supposedly of pre-Cambrian age. The ore bodies consist of two roughly unsymmetrical troughs which are parallel to what is taken to be the bedding of the limestone. The ores consist chiefly of franklinite, willemite, and zincite. The gangue consists of calcite, rhodonite, garnet, pyroxene and hornblende. The texture of the ore is highly granular and in much of it foliation is strongly marked. The ore bodies are layers or stratiform masses containing a varying mixture of the three ore minerals and calcite, enclosed or cased by coarsely crystalline white limestone. The ore and the country rock are in general not sharply separated by definite walls, but the calcite of the rock is intergrown with that of the gangue, and in many places there is a gradual passage from workable ore thru lean material into barren rock without the slightest suggestion of a physical break. Both the en-

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1/ Spencer, A. C. The Mine Hill and Sterling Hill Zinc Deposits, Sussex County, New Jersey.

closing rock and the ore show a rather well marked and persistent lamination that corresponds in appearance and attitude with the platey structure of the gneiss occurring thruout the general area outside of the white limestone area. In the ore this foliation is more strongly marked than in the limestone, because of the contrasting colors of the component minerals, but wherever foreign materials are present in the limestone the laminated effect is obvious. Completeness of foliation depends on the variations in the proportions of several constituent minerals segregated in different parts of the vein. The mineral grains on the borders of adjacent layers or plates interlock,so that the entire mass is closely knit into a solid whole.

Theories of origin for these deposits vary considerably. Kemp[1/] advances the possibility that they were original manganese, zinc, and iron deposits in limestones, much as many Siluro-Cambrian limestone beds are seen today, and that in the general metamorphism of the region it became changed to its present condition. From the association of granitic intrusion the igneous origin is suggested by the contact minerals near them. Victor Mon-

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1/ Kemp, J. F., Ore Deposits of the United States and Canada, Third Edition, p. 256.

heim's[1] work shows the possibility of a direct separation of anhydrous zinc silicate from solution at high temperature, while the hydrous salt results at lower temperature.

Spencer supports the magmatic theory in his report for the New Jersey Survey. He argues that the present characters of the ore masses and wall rocks originated contemporaneously, because the two are not sharply separated; so that the deposits must have been introduced either before or during the metamorphism of the containing rocks and the igneous rocks which are now gneisses. He favors the view that the lean ore of Sterling Hill was probably deposited by magmatic waters which permeated and replaced the limestone, and while the richer portion of the ore may have been formed in the same way, there is also the possibility that the main ore body at Sterling Hill and the mass of ore at Mine Hill were injected bodily into the limestone, like igneous intrusions. Evidence favoring igneous origin, as presented by Spencer, appears in the fact that the pegmatites do contain well crystallized minerals now found in the ore bodies, suggesting that they brot the ores in. The association of zinc with manganese

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[1] Cited by J. F. Kemp, Ore Deposits of United States and Canada, 3rd Edition.

and iron, the combination of these metals in the condition of oxide, and the mineralogic similarity between franklinite and magnetite suggest a close analogy between the zinc deposits and those of iron ore occurring thruout the area occupied by pre-Cambrian rocks in New Jersey and southeastern New York. Taken as a whole, Spencer believes that the resemblances lead to the view that the ore bodies here are to be classified with the occurrences of magnetite, and to be regarded as a variety of these ore deposits differing from the ordinary types mainly in the unusual amount of zinc and manganese which they contain.

Whatever may have been the origin and form of these deposits, it is certain that anamorphic influences, both of contact and dynamic nature, have been active in bringing them into their present condition. Of the changes, those of a physical nature are the most apparent for the ore is now strongly foliated and the ore bodies themselves have been deformed into trough-shaped forms. Not knowing the original mineralogical character, little can be stated regarding the chemical and mineralogical changes involved.

Production of Anamorphosed Zinc and Lead Deposits.

Anamorphosed zinc deposits have contributed much to the mineral wealth of New Jersey and to the United States. The deposits at Deer Isle, Maine, are unimportant, having produced only about 900 tons of ore. The deposits at Franklin Furnace have produced 15,128 tons of zinc ore, or 5.57% of the total production for the United States in 1911.

GOLD AND SILVER.

General Statement.

The search thru the literature failed to reveal any descriptions of gold or silver deposits that were formed during anamorphism or modified by it to any great extent. Both gold and silver occur associated with many of the copper deposits described along the Appalachians, and some of those in the West. The gold disseminated ores in the pre-Cambrian of the Homestake mine of the Black Hills region of South Dakota are believed to be in part modified by anamorphism, tho even this seems doubtful.

Gold and Silver Associated with the Copper Deposits of the Appalachians.

Gold and silver appear to be closely associated in varying amounts, usually small, in all of the deposits described under the anamorphosed equivalents of fissure veins of the replacement type and ore disseminated along fracture zones. The gold was probably associated with the pyrite and other sulphides. Just what effects anamorphism has had can not be stated, for in their present form they are clearly the result of katamorphic al-

terations of the superficial portions of these anamorphosed ore bodies.

The most important deposit of this type occurs at the Gold Hill deposit, North Carolina. These deposits have furnished considerable gold both from the oxide zone and the sulphide zone.

Gold Deposits of the Homestake Mine, South Dakota.[1/]

These ore bodies occur in Algonkian slates. The ore bodies are rather ill-defined masses of rock sufficiently impregnated with gold to pay for working, but otherwise hardly to be distinguished from the country rock in which they occur. They are singularly barren of the usual ore minerals. The gold occurs in so finely divided a state as to be rarely visible, even with a magnifying glass. Besides gold the only other metallic minerals are pyrite and arsenopyrite -- the former by far the more important -- which are irregularly disseminated thru the ore, generally in very small crystals. The gangue minerals consist chiefly of quartz, of various periods of formation with calcite, dolomite, tremolite and garnet. Where the relative age of the gold could be determined it was

1/ Irving, J. D. Economic Resources of the Northern Black Hills. U. S. Geol. Survey, Prof. Paper 26, 1904.

found to be of later formation than the gangue minerals.

It is believed that the solutions rose along planes of movement and were precipitated as iron sulphide and gold. No definite evidence as to the source of material is known. The ore is of distinctly later formation than the garnet and associated minerals, and the latter are seen under the microscope to have been formed since the dynamic action which produced lamination or schistosity in the rocks. Several later periods of mineralization followed the intrusion of the rhyolite.

The general conclusions drawn by Irving from a study of some specimens of ore appear as follows:--

1. There have been successive periods of movement during and since the metamorphism of the Algonkian series.

2. There have been successive periods of mineralization which occurred later than the metamorphism of the series. Others may have occurred prior to metamorphism, but of these we have no record.

3. Tho no definite evidence is at hand to show that the gold was introduced into ores after the metamorphism of the rock, it seems most reasonable to refer it to this period of mineralization.

Production of Anamorphosed Gold and Silver Deposits.

Production from the Gold Hill deposits has amounted to $3,000,000 worth of gold, while no record is had of the others. The production of the Homestake Mine, the chief producer, has yielded something like 1,468,263 tons of ore valued at $5,251,454 for the year ending June 1, 1911. The total production of this mine and others similarly located is not given in the Mineral Resources.

SUMMARY AND CONCLUSION.

Iron.

In the production of iron, anamorphism is found to have played a very unimportant rôle, for the reason hinted in the beginning of the paper, i. e., that anamorphism, by definition, acts only on rocks, ore bodies, etc., which have previously been formed. It has been found that anamorphic equivalents of residual limonites, sedimentary carbonate and silicate rocks, iron oxides, and secondarily infiltrated limonites exist, and of these, those of the anamorphosed iron oxide ore bodies are the most important commercially, producing about 7% of the Lake Superior iron ores.

Where the ore was originally limonite or hematite the chief chemical changes are dehydration and deoxidation to some extent. Where carbonate or silicate rock, the chemical changes are partial oxidation, with decarbonation, dehydration, and silication. Recrystallization is important thruout. The mineralogical changes consist of limonite and hematite to specular hematite or magnetite with various amphiboles. Physically there is a great reduction of pore space, the ore becoming hard, dense, and in part crystalline and schistose. Banding is a common

characteristic of the anamorphosed iron carbonate and silicate rocks.

This contrasts strongly with the katamorphic effects on iron-bearing rocks where we have the percentage of iron increased both by the elimination of other substances and by the actual carrying of iron in solution and deposited in favorable places. The elimination of other substances is by far the most important, whereas recrystallization predominates under anamorphic conditions.

Thus the concentration of iron by anamorphism is only relatively due to the loss of water and oxygen and the reduction of pore space, which does not increase the actual percentage of iron, there being little evidence for the transfer and segregation of iron.

Copper.

Various types of copper deposits have been described which are believed to have been formed during anamorphism and as a result of it. Copper of this mode of origin is now found disseminated in amphibolitic schists, or as replacements of limestones in contact with amphibolitic schists, and disseminated in shear zones. In each case the copper is thot to have existed as extreme-

ly finely-disseminated copper sulphide in the basic diorites, diabases or gabbros now found as amphibolitic schists. It is believed that under the processes of deep-seated alterations to which these rocks were subjected the copper was taken in to solution and segregated in bunches, nests, and stringers, in the schists, as in some cases the copper-bearing solutions travelled somewhat farther and replaced adjacent limestones or became precipitated as disseminations along shear zones. In all cases the contained water trapped in the rock and the heat and pressure produced by dynamo-metamorphism are thot to be the chief agents in bringing about the chemical changes, which, so far as known, appear to be solution with some transfer and precipitation. Tho little is definitely known regarding the true origin of these ores, it seems likely that anamorphism has played the major part in their formation, and yet when one looks for definite and convincing evidence to prove their origin one fails to find it, and the modes of genesis given in each case are chiefly the opinions of the men who have studied them.

Anamorphosed equivalents of previously formed copper deposits were also noted, the most important of this group being the anamorphosed equivalents of replacement veins or of disseminated ores along fracture zones.

An example of an anamorphosed contact deposit containing some copper was also found. These types constitute an important source of copper for many of the eastern Appalachian states. The chief chemical changes involved are chiefly recrystallization involving solution and reprecipitation with rearrangement without the introduction of new elements. The physical changes involve an orientation of the ore bodies parallel or nearly parallel to the schistosity of the country rock, with a mashing, crushing, cementation, and the production of a laminated structure especially along the outer edges of the ore bodies. All traces of hydrothermal alterations, or evidences of vein filling such as banding, crustification, and so forth, have been obliterated.

The production of the preceding class of copper deposits is practically nil thus far. That of the latter is somewhat more abundant, one deposit alone producing about 18,850,976 pounds of copper, or 1.72% of the total production of the United States for 1911.

Zinc and Lead.

No uniformity is found in the anamorphosed equivalents of zinc deposits found described in the literature. The first, that at Deer Isle, is thot to be of undoubted

contact origin. The chemical changes are thot to have been simply a recrystallization and rearrangement of the minerals present. The physical changes are supposed to be the greatest, for the ore bodies now parallel the schistosity, they consist of interlaminated sheets of sulphide and schist, and the garnets and ore minerals are crushed and recemented.

With regard to the Franklin Furnace deposit little regarding the chemical and mineralogical changes is known for the original nature of these is still in doubt. Apparent anamorphic effects are the production of a laminated structure and the present trough-shaped character of the ore bodies. Their commercial importance is great, being one of the chief producers of zinc and manganese for the United States.

Gold and Silver.

Knowledge of the anamorphic effects on deposits of this kind is scarce and indefinite. In one, the Gold Hill mine of North Carolina, the gold is associated with other sulphides and quartz, and is not the chief producing mineral. This ore body is believed by Emmons to be the anamorphosed equivalent of a fissure vein of the replacement type. Anamorphism has not effected the

concentration of gold, at least not to any great known extent.

The gold deposits of the Homestake mine are important commercially, but the effects of anamorphism are not known, the ore probably being introduced earlier than the chief period of anamorphism.

Looked at broadly it can be seen that this investigation has shown that anamorphism has accomplished little in the way of concentration of our six chief metals into valuable ore bodies. This was to be expected from the characteristics of anamorphism presented in the beginning of this paper. Anamorphism, acting on previously formed materials, works them over, changing chiefly their physical form with moderate chemical and mineralogical changes. It is interesting to note in this connection the close similarity between the anamorphism of sedimentaries and ore bodies. In both little new material is added and very few elements are eliminated. The chief changes are a recrystallization of the materials present forming new minerals, which are more stable under the new conditions. The physical changes are marked in both. Concentration where possible could only be realized by a segregation during the process of recrystallization. This has been inferred to take place in a few cases, chiefly in those of copper

associated with amphibolitic schists, but the deposits are of low grade and of little importance at the present time. Anamorphism then can be said to change the manner of occurrence of ore bodies, but does little actual concentrating.

APPROVED:

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